BEHAVIOUR OF CONCRETE UNDER HIGH VELOCITY IMPACT

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BEHAVIOUR OF CONCRETE UNDER HIGH VELOCITY IMPACT

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Abstract

Steel Fibre reinforced concrete (SFRC) has shown improved engineering properties such as Flexural strength and shattering resistance etc. in comparison to Plain or Reinforced Cement Concrete. This technique has been recommended for the construction of explosive/ammunition storage buildings and processing areas. Experimentation have been undertaken to investigate its behaviour against high velocity impact of projectiles. Specially designed model projectiles of calibre 30 mm were made to interact with different types of concretes such as PCC, SFRC and SFRC reinforced with steel rods, with varying velocities ranging from 50 to 450 m/s. Transient behaviour of the interaction has been recorded with high speed photography. In the process of high velocity impact concretes are damaged differently, showing cracking, spalling or scabbing or their combinations. Behaviour of various types of concretes against high velocity impact and their comparative performance have been discussed in this paper.

Introduction

Conventional plain cement concrete although in use for decades but has limited scope of application due to its low tensile strength and poor ductility. In practice, concrete is normally reinforced with steel bars or mesh to withstand tensile stresses. Advancement in material science and engineering has led to the development of a composite construction material named Steel Fibre Reinforced Concrete. It consists of conventional concrete or mortar, reinforced by random disposal of short fine steel fibres of specific geometry. This concrete has better tensile strength, toughness and ductility vis-a-vis plain or reinforced concrete.

To study the behaviour of this concrete against high velocity impact of the projectile extensive work has been carried out at Terminal Ballistics Research Laboratory, Chandigarh, India and the detailed investigations are reported in the following paragraphs.

Experimental Set Up

Impact studies on concrete targets were carried out with specially designed projectiles of calibre 30 mm. The projectiles were of CRH value one and their length was 150 mm. These projectiles were hollow and filled with high explosive substitute. The projectiles were made of EN-24 material. They were in the weight group of 472 ± 4 gm. These projectiles were projected horizontally with 30 mm launcher at desired velocity. Velocity of the projectile was varied from 50 to 470 m/sec by changing the propellent weight. Figure 1 shows an assembled round alongwith its components.

Three types of concrete blocks i.e. PCC (Plain Cement Concrete), SFRC (Steel Fibre Reinforced Concrete) and SFRC reinforced with steel rods were used as targets. Although blocks of different types were having different compositions but they were of the same size i.e. 75 x 75 x 17.5 cm. Compre-ssive strength of each block was measured by non-destructive method before firing and it was found to be in the range of 350 ± 20 Kg/Cm . Details of these blocks have been shown in Figures 2 (a,b,c).

Multiple Spark Photography was used for seeing the flight of the projectile in pre and post impact stages. The transient behaviour of the target during its interaction with the projectile was also recorded. A pair of screens connected with microsecond counter was placed in front of the block (target) for measuring the velocity of the projectile, just before impact. In every experimental trial concrete target was placed vertically, facing muzzle of the launcher. The projectile was allowed to hit at the centre of the block and only one trial was conducted on each block.

All experiments were conducted for normal attack only. Figure 3 shows the set up of the experiment.

Observation

After completion of each experiment the projectile was recovered and examined carefully for any damage sustained. In no case the projectile was found to have any type of damage. After each firing, the target was also examined and it was found to have inculcated a crater of almost conical in shape with circular base, on the front surface of the block and the apex inside. The damage was assessed in terms of the penetration i.e. the depth of the apex from the front surface, dia of the crater (mean of the two values measured at right angles) and the volume of the crater in each of the experiments. The data for different impact velocities of projectile have been given in Table I, II and III for PCC, SFRC and SFRC reinforced with steel rods, respectively. At lower velocities all the three types of concrete targets sustained damage on the front surface only and no effect on the rear was recorded. But as the impact velocity was increased a stage was reached when cracks were developed on the rear of the concrete targets. Figures 4, 5, 6 show the cracks developed on the rear of three types of blocks. For further increase in the impact velocity, a scab was thrown off from the rear of the block. In between these two stages a critical stage was also observed where scab a big chunk was found hanging at the rear surface and was about to be detached. Figure 7 and 8 shows the critical stage of the scabbing. Fig 9 shows sequentially the scab flying away from the rear of the block. The scab was not one mass of concrete but shattered pieces leaving a crater of conical shape. These observations were similar for all types of concretes. Figure 10, 11 and 12 show the crater formed after the scab was thrown off from three types of blocks. It is evident from these figures that the crater were of different sizes for different types of concrete blocks. The dia of the crater on the rear was measured along two perpendicular axes and mean taken. It was a significant observation that the dia of the crater on the rear side was always bigger than the dia formed on the front side. Values of the depth and volume of the crater so formed on the rear of the three types of blocks were also recorded. The data has been given in Table IV.

Discussion

To evaluate the comparative behaviour of three types of concretes, based on the damage inculcated on them, graphs were plotted taking impact velocity on x axis and penetration, crater dia and volume of the crater formed on the front surface on Y axis. These have been shown in Figure 13, 14 and 15. It is evident from Figure 13 that SFRC reinforced with steel rods offered maximum resistance to penetration while PCC the minimum. But no marked difference in the penetration behaviour of three types of concrete was recorded upto a velocity of 160 m/sec. Figure 14 and 15 show the variation of crater dia and crater volume of three types of concretes with impact velocity of the projectile. These two graphs also show that for impact velocity upto 160 m/sec, the variation in these two parameters is almost the same for three types of blocks. It is only after this value of impact velocity the curves diverge from each other.

A close look to these graphs reveals that SFRC reinforced with steel rods offers maximum resistance to the impact of high velocity projectiles sustaining minimum damage on the front surface followed bySFRC and PCC in sequence.

Regarding, scabbing behaviour of concretes it has already been mentioned in observation column that the damage incurred due to scabbing on the rear surface for any concrete is always greater than its respective front surface damage. For having a comparison of the scabbing behaviour of three types of concretes histogram of recorded values of four parameters i.e. critical velocity of scabbing, volume, dia and depth of crater formed on the blocks after the scabs were thrown off were plotted. This has been shown in Fig 16. This histogram clearly shows that out of three types concretes, it is PCC which suffers scabbing most easily i.e. at the lower impact velocity than SFRC, and SFRC reinforced with steel rods, which follow in sequence. Damage caused due to scabbing also follows the same sequence and volume of the crater formed in three types of concrete i.e. SFRC reinforced with steel rods, SFRC and PCC are in the ratio 1:1.4:4.5 while dia bears up a ratio 1:1.8:2.3 and depth of penetratioin 1:1.2:1.5.

Conclusion

Based on above investigations superiority of steel fibre reinforced concrete over PCC against impact of high velocity projectiles has been established. However, if this concrete is further reinforced suitably with steel rods, will provide more immunity against the said attack.

Acknowledgement

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We pay our solemn gratitude to our Director, Shri M Balakrishnan for his able suggestions during the course of work and permission to publish the paper in the Proceedings of the 24th Seminar on Explosive Safety.

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TABLE I- DAMAGE DATA OF PCC TARGET

Sr.No	Impact Velocity (m/sec)	Penetration (mm)	Av.Dia. (cms)	Measured Volume (Cu.cc)
1.	44.69	8.8	2.75	30.62
2.	71.91	15.0	6.10	46.01
3.	73.98	15.9	8.25	57.11
4.	91.93	18.8	8.75	66.16
5.	105.11	26.0	11.75	120.03
6.	117.83	27.9	11.25	120.86
7.	128.40	29.5	11.25	128.31
8.	140.63	34.1	12.75	173.01
9.	149.69	35.8	13.50	253.11
10.	166.33	37.0	12.25	176.32
11.	215.02	55.25	17.50	554.63
12.	223.71	64.2	16.35	672.01
13.	225.30	62.5	20.35	668.83
14.	255.80	65.3	19.50	513.10
15.	319.50	80.0	23.00	1138.20
16.	300.07	86.2	19.00	1307.90
17.	337.12	91.7	22.75	1090.10
18.	347.86	90.5	24.00	1248.00 (Limiting case of scab)
19.	366.28	85.7	26.25	Scabbed

TABLE II - DAMAGE DATA OF SFRC TARGETS

Sr.No	Impact Velocity (m/sec)	Penetration (mm)	Av.Dia. (cms)	Measured Volume (cu. cc)
1.	72.73	16.0	7.00	36.42
2.	86.31	19.2	6.75	45.50
3.	110.06	25.5	10.75	97.66
4.	160.18	36.7	12.75	228.10
5.	230.51	42.4	14.40	284.00
6.	269.23	59.0	17.00	481.80
7.	321.10	78.0	17.50	563.74
8.	374.53	90.3	16.00	461.96 (Limiting case of scab)
9.	436.59	80.0	18.20	Scabbed

TABLE III - DAMAGE DATA OF SFRC TARGETS
REINFORCED WITH STEEL

Sr.No	Impact Velocity (m/sec)	Penetration (mm)	Av.Dia. (cms)	Measured Volume (cu. cc)
1.	60.00	14.5	5.25	21.50
2.	38.01	21.7	6.15	57.55
3.	114.89	28.4	10.00	136.59
4.	164.70	32.0	10.50	157.26
5.	223.25	48.5	15.75	413.93
6.	234.46	51.8	14.00	240.06
7.	265.32	59.5	15.25	703.60
8.	338.86	80.0	14.50	281.40
9.	423.96	90.3	16.50	531.45 (Limiting case of scab)
10.	462.55	114.0	26.00	Scabbed

TABLE IV - DATA OF DAMAGE DUE TO SCABBING ON
DIFFERENT TYPES OF CONCRETE

Sr No	Type of Block	Scabbing Velocity (m/sec)	Dia.of Scab (cms)	Depth of Scab (cms)	Volume of scabbed portion (cu. cc)
1.	PCC	366.80	41.00	9.7	6374
2.	SFRC	436.59	32.75	8.0	1970
3.	SFRC + RCC	462.55	18.00	6.6	1407

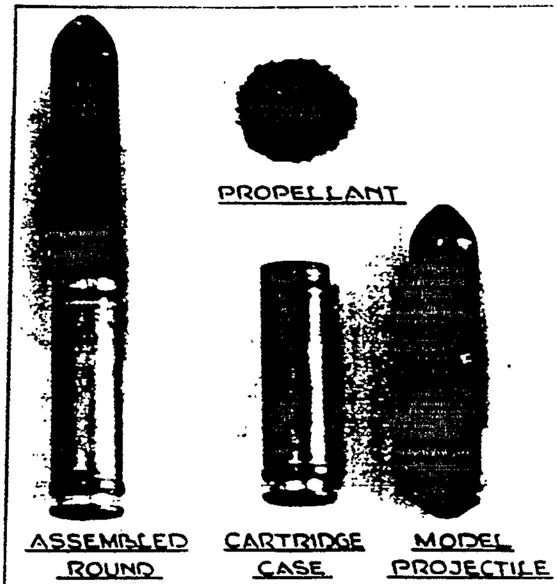
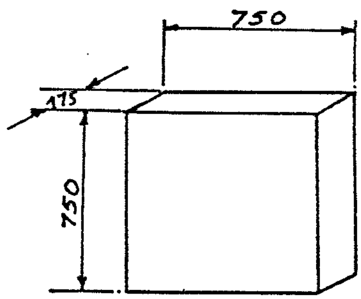


FIG.1:- ASSEMBLED ROUND AND ITS COMPONENTS



P C C

MIX PROPORTIONS (PCC)

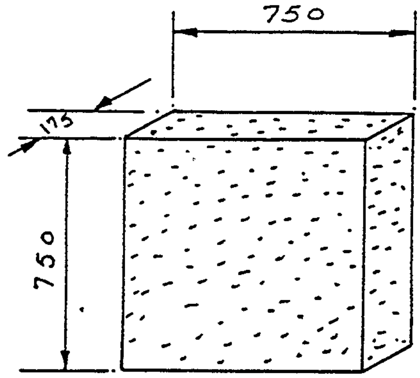
GRADE OF CONCRETE - M 30

QUANTITY OF MATERIALS PER

CU.m OF CONCRETE

1. CEMENT — 530 Kg
2. SAND — 619.5 Kg
3. COARSE AGGREGATE — 309.7 Kg (PASSING THROUGH 10 mm & RETAINED ON 4.75mm); 619.3 Kg (PASSING THROUGH 20 mm & RETAINED ON 10 mm)
4. WATER — 219.7 LITRES
5. SUPER PLASTICIZER — 5.3 Kg. (1% BY WEIGHT OF CEMENT)

FIG 2(a) :- SKETCH SHOWING DETAIL OF PCC



SFRC

MIX PROPORTION (SFRC)

GRADE OF CONCRETE-M 30

QUANTITY OF MATERIALS PER Cu.m OF CONCRETE.

1	CEMENT	- 530 Kg
2	SAND.	- 603.5 Kg
3.	COARSE AGGREGATE	301.7 Kg (PASSING THROUGH 10 mm & RETAINED ON 10 mm) 603.5 Kg (PASSING THROUGH 20 mm & RETAINED ON 10 mm)
4.	WATER	- 220 LITRES.
5.	SUPER PLASTICIZER	- 5.3 Kg. 1% WT. OF WATER
6.	STEEL FIBRE	98.125 Kg (1.25% BY VOLUME ON CONCRETE) ASPECT RATIO - 80 (LENGTH - 36 mm, Ø - 0.45 mm)

FIG. 2(b):- SKETCH SHOWING DETAIL OF SFRC.

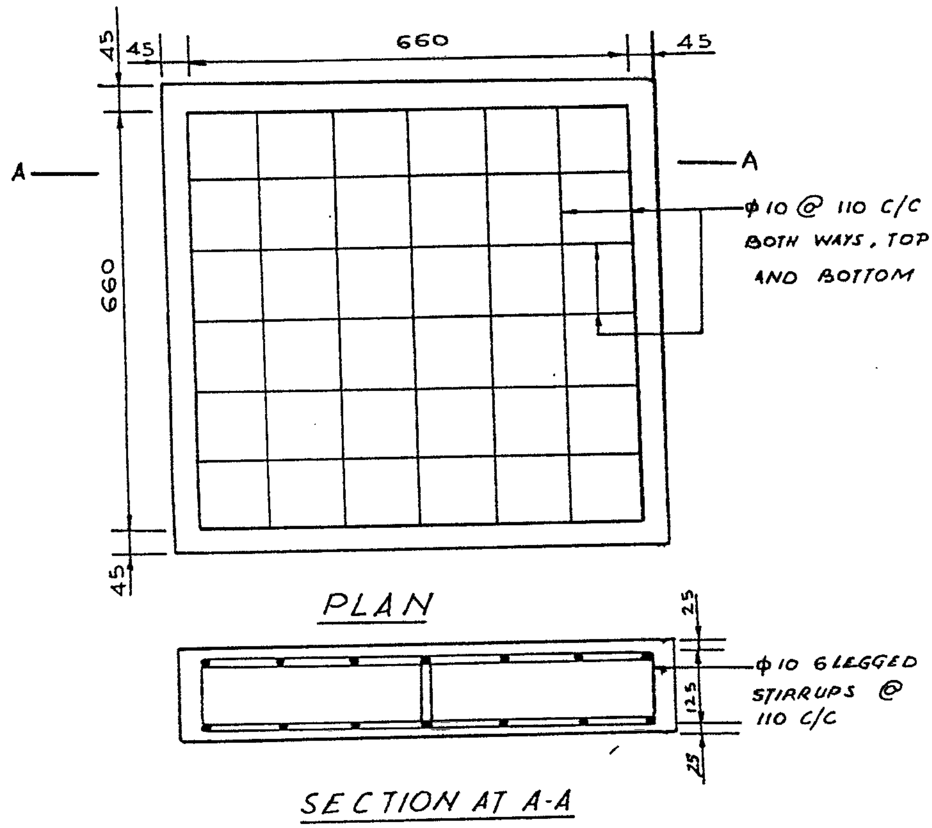


FIG. 2.(C) SKETCH SHOWING DETAILS OF SFRC REINFORCED WITH STEEL RODS

DIMENSIONS IN mm

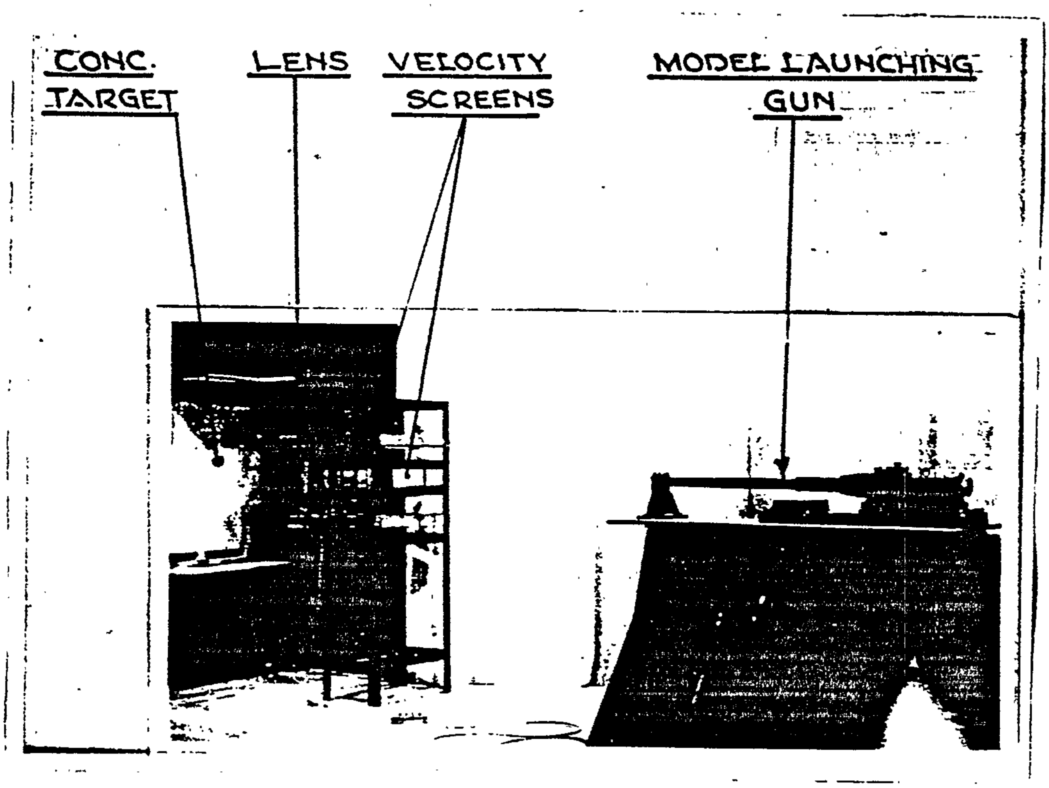


FIG.3 : EXPERIMENTAL SET UP

FIG.4. CRACKS DEVELOPED ON THE REAR SIDE OF PCC TARGET

FIG.5. CRACKS DEVELOPED ON THE REAR SIDE OF SFRC TARGET

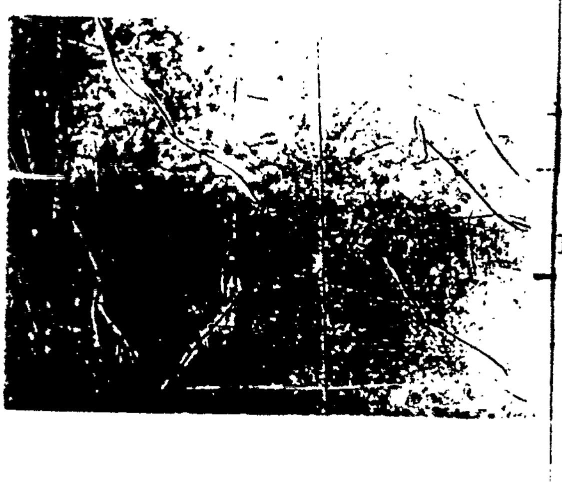


FIG.6. CRACKS DEVELOPED ON THE REAR SIDE OF SFRC AND RE-INFORCED WITH STEEL RODS.

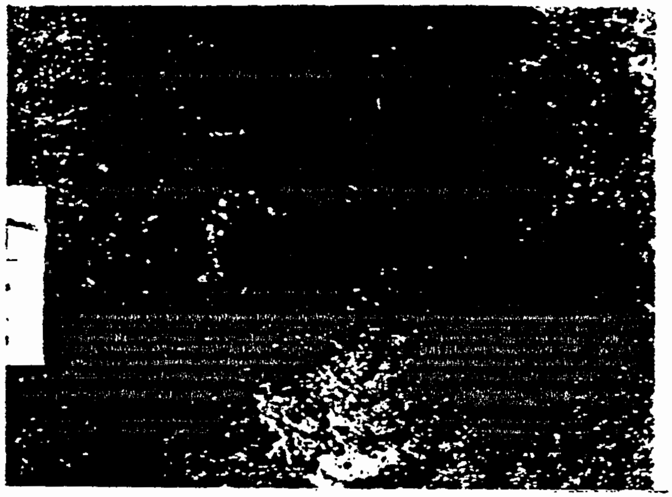


FIG.7. PROJECTILE STRUCK IN THE SFRC TARGET AT THE CRITICAL STAGE OF SCABBING

FIG.8. A SCAB ABOUT TO BE FLOWN OFF FROM THE REAR OF SFRC TARGET

17

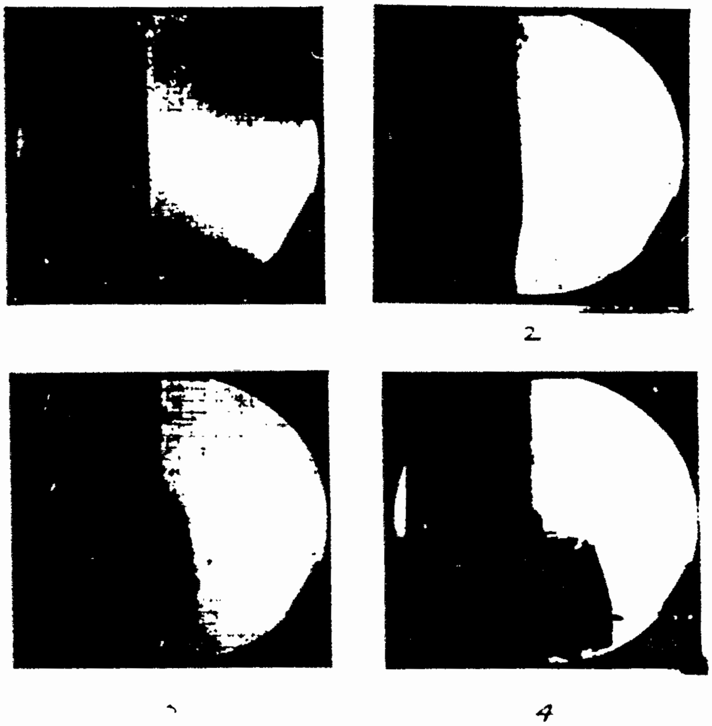


FIG.9. SEQUENCIAL RECORD SHOWING EMERGENCE OF SCAB FROM THE REAR OF TARGET No.AN-2(SFRC+RCC) WHEN HIT BY PROJECTILE WITH AN IMPACT VELOCITY OF 494.11 m/sec.

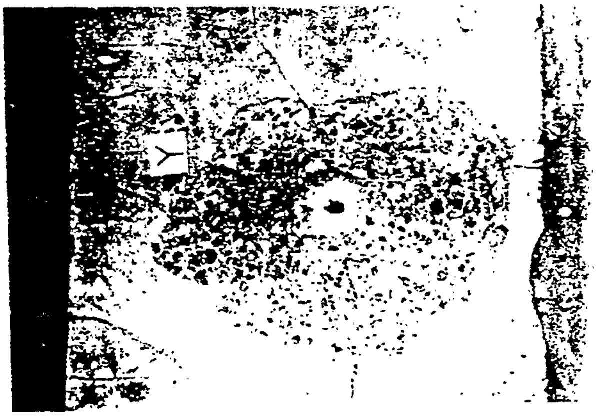


FIG.10. CRATER FORMED ON THE REAR SIDE OF PCC TARGET AFTER SCABBING.

FIG.11. CRATER FORMED ON THE REAR SIDE OF SFRC TARGET AFTER SCABBING.

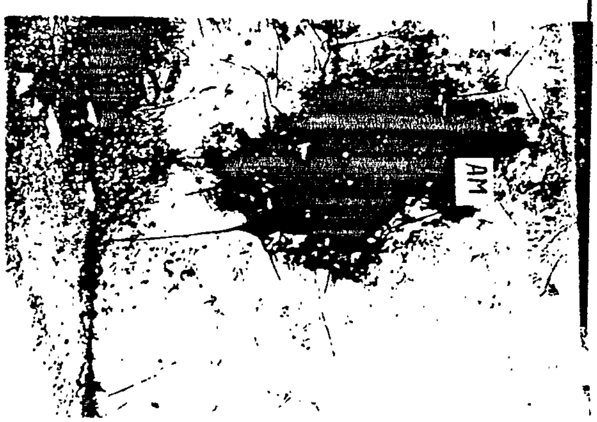


FIG.12. CRATER FORMED ON THE REAR SIDE OF SFRC REINFORCED WITH STEEL RODS TARGET AFTER SCABBING.

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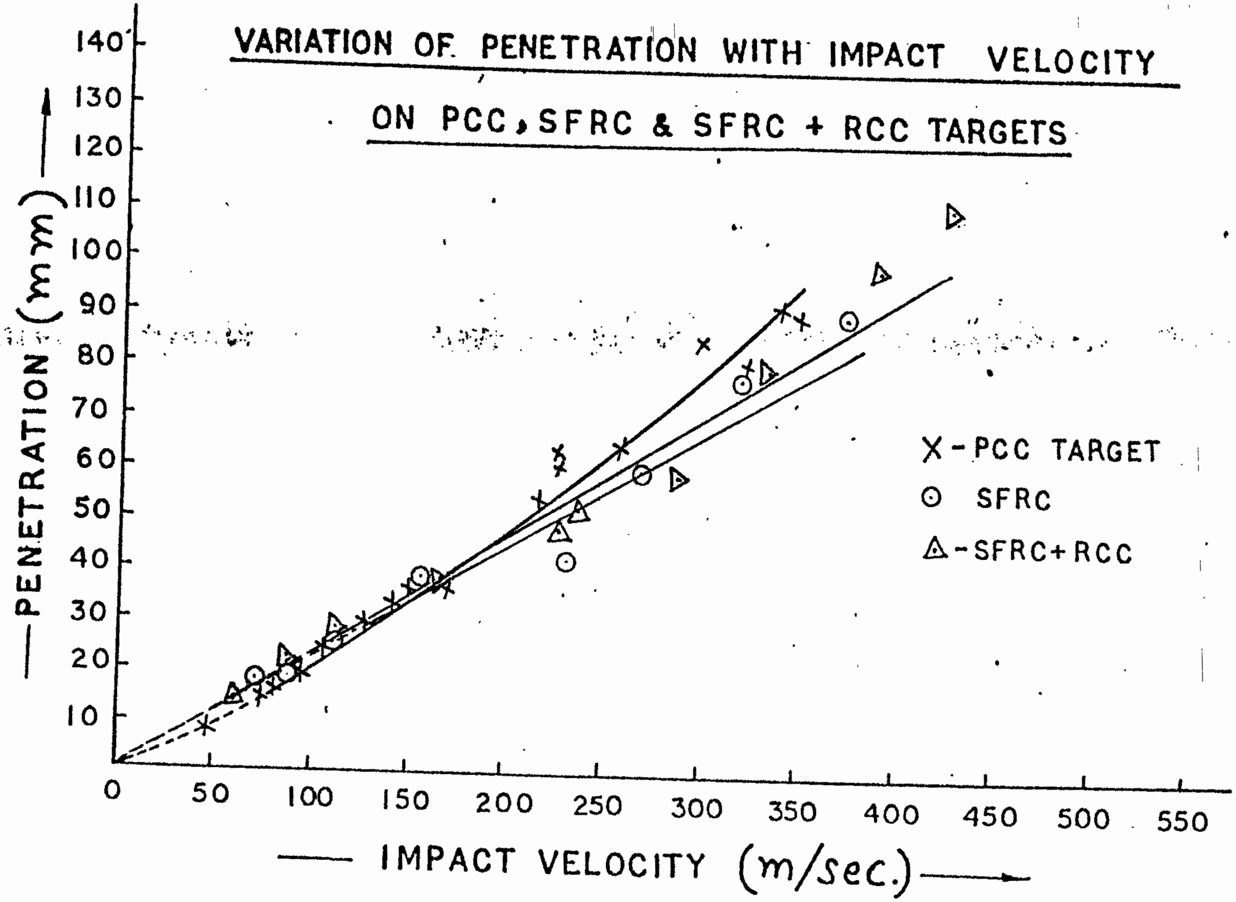
VARIATION OF PENETRATION WITH IMPACT VELOCITY
ON PCC, SFRC & SFRC + RCC TARGETS
— PENETRATION (mm) →
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
450
500
550
— IMPACT VELOCITY (m/sec.) →
X - PCC TARGET
⊙ SFRC
△ - SFRC+RCC

FIG. 13

VARIATION OF CRATER DIA INCULCATED ON PCC, SFRC & SFRC + RCC TARGETS WITH IMPACT VELOCITY

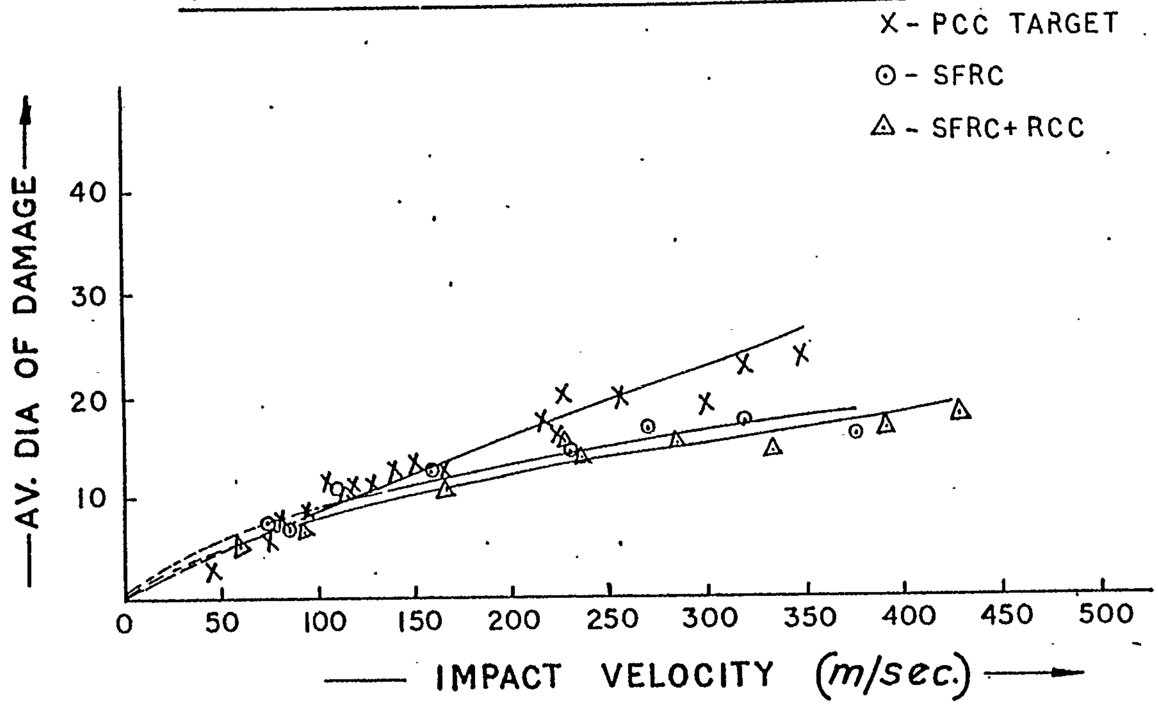

FIG. 14

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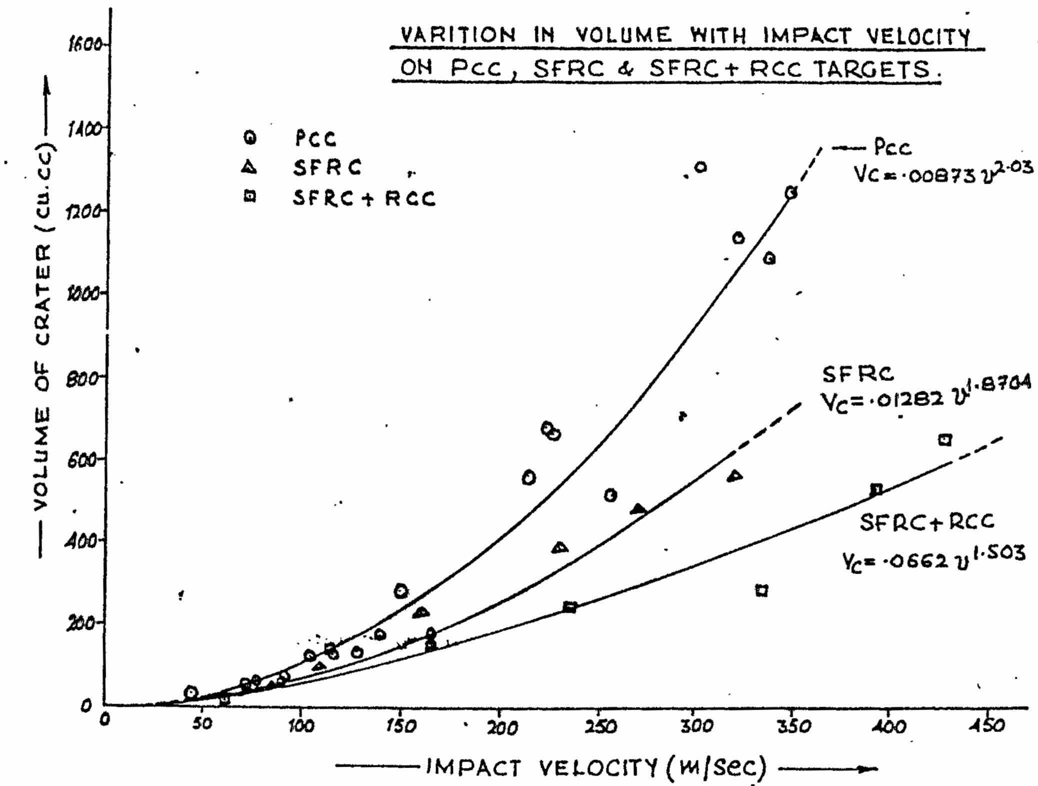

VARITION IN VOLUME WITH IMPACT VELOCITY
ON Pcc, SFRC & SFRC+RCC TARGETS.
PCC
SFRC
SFRC+RCC
Pcc
Vc = ·00873 v^2·03
SFRC
Vc = ·01282 v^1·8704
SFRC+RCC
Vc = ·0662 v^1·503
VOLUME OF CRATER (cu.cc)
IMPACT VELOCITY (m/sec)
0
200
400
600
800
1000
1200
1400
1600
50
100
150
200
250
300
350
400
450

FIG. 15

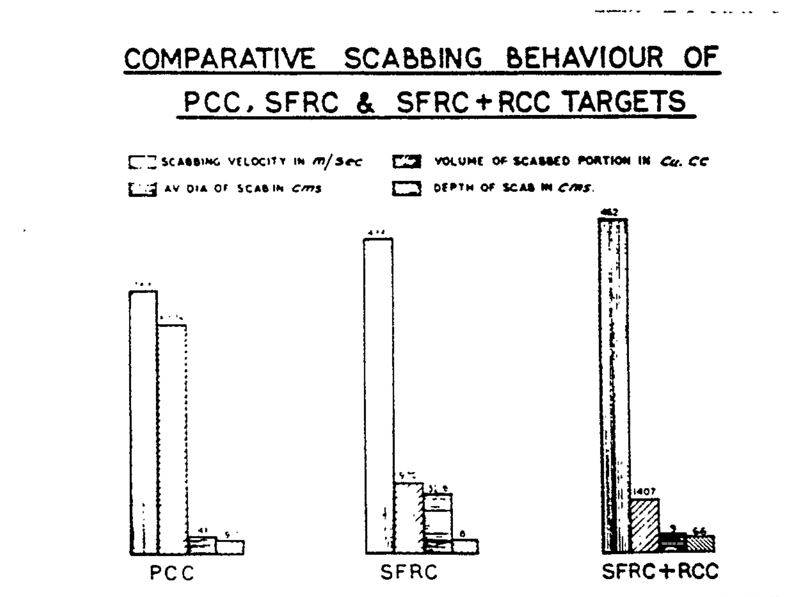

FIG.16. HISTOGRAM SHOWING COMPARATIVE SCABBING BEHAVIOUR OF PCC, SFRC AND SFRC REINFORCED WITH STEEL RODS.